

**ANNUAL PROGRESS SUMMARY**  
**Project period January 1, 2004 – December 31, 2004**

**TITLE:** THE QUATERNARY GEOLOGIC FRAMEWORK FOR THE CITY  
OF SEATTLE AND THE SEATTLE-TACOMA URBAN CORRIDOR

**Cooperative Agreement Number:** 01HQAG0017

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**NEHRP Element:** I, Pacific Northwest region   **Keywords:** Geologic Mapping,  
Surficial Deposits, Age Dating, Tectonic Structures, Urban Geology

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### ABSTRACT

Our investigations during this project year represent the continuation and development of a wide range of tasks that focus on the Quaternary geologic framework of the Seattle area. Major accomplishments and expansion of scope this year include multiple 7.5-minute geologic maps into or through the USGS technical review process, completion of data acquisition and field work throughout the City of Seattle, continued progress on 3-D digital map products for Seattle, and free public Internet access of our entire geologic database, currently numbering over 65,500 exploration sites. Our emphasis on Quaternary geologic data is critical for any geologic or seismic-hazard study because most of the central Puget Lowland has a recent sedimentary cover one hundred to over one thousand meters thick.

During this project year, we accomplished the following tasks:

- Completed USGS technical review (through Team approval) of two SIM-series 7.5-minute maps at 1:24,000 scale in the Tacoma area;
- Submitted 4 maps for USGS technical review: surficial geologic maps of the Seattle SE and NE quadrangles at 1:12,000 scale, Composite geologic map of Seattle at 1:24,000 scale, and surficial geologic map of the Issaquah quadrangle at 1:24,000 scale;
- Continued population of a database of existing subsurface geologic and geotechnical data, with an additional 10,000 individual records (points) of subsurface geologic information (now 65,500 total);
- Multiple abstracts, several journal manuscripts, and many fieldtrip guidebooks;
- Response to requests for information from USGS scientists within and outside of the Earthquake Program, other Federal agencies, local governments, private consultants, and the public;
- Short courses, field trips, technical presentations, and public presentations;
- Hosted a workshop on the Seattle fault and geology of Mercer Island for its employees;
- Three-fold leveraging of USGS NEHRP funds for 2004 that has expanded both the data collection and the geographic scope of the project;

- Upgraded from the Seattle-Area Geologic Mapping Project to a research center at the University of Washington, the Pacific Northwest Center for Geologic Mapping Studies;
- Began scanning boring logs and documents to create linked images to enhance our web access.

## BACKGROUND

Our investigations during this sixth year of the project represent the continuation and development of a wide range of tasks that focus on the Quaternary framework of the Seattle area. We have defined five major components to develop this framework and to disseminate the resulting information:

1. Develop the regional stratigraphy and chronology for the central Puget Lowland;
2. Create a subsurface geologic database for the City;
3. Prepare new surficial geologic maps of the City;
4. Develop the geologic model (3-D map and database) of the City; and
5. Provide education and technical outreach.

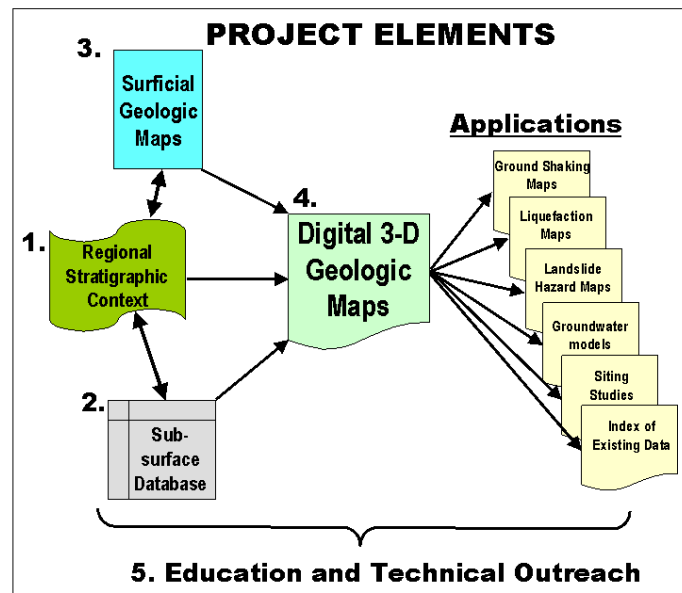


Figure 1: Elements of the Seattle Geologic Mapping Project

The surficial and 3-D geologic mapping in the four quadrants of the City of Seattle (Figure 2) provides the framework for the overall project. The sequence of map products is as follows (3-D maps are anticipated to lag their surficial counterparts by two calendar years):

MAP QUADRANT	SURFICIAL GEOLOGIC MAP
Seattle SW	2001 (in review, USGS WPG)
Seattle NW	2002 (in press, USGS WPG)
Seattle SE	2005 (map in review 12/04)
Seattle NE	2005 (map in review 10/04)
Composite Seattle	2005 (map in review 12/04)

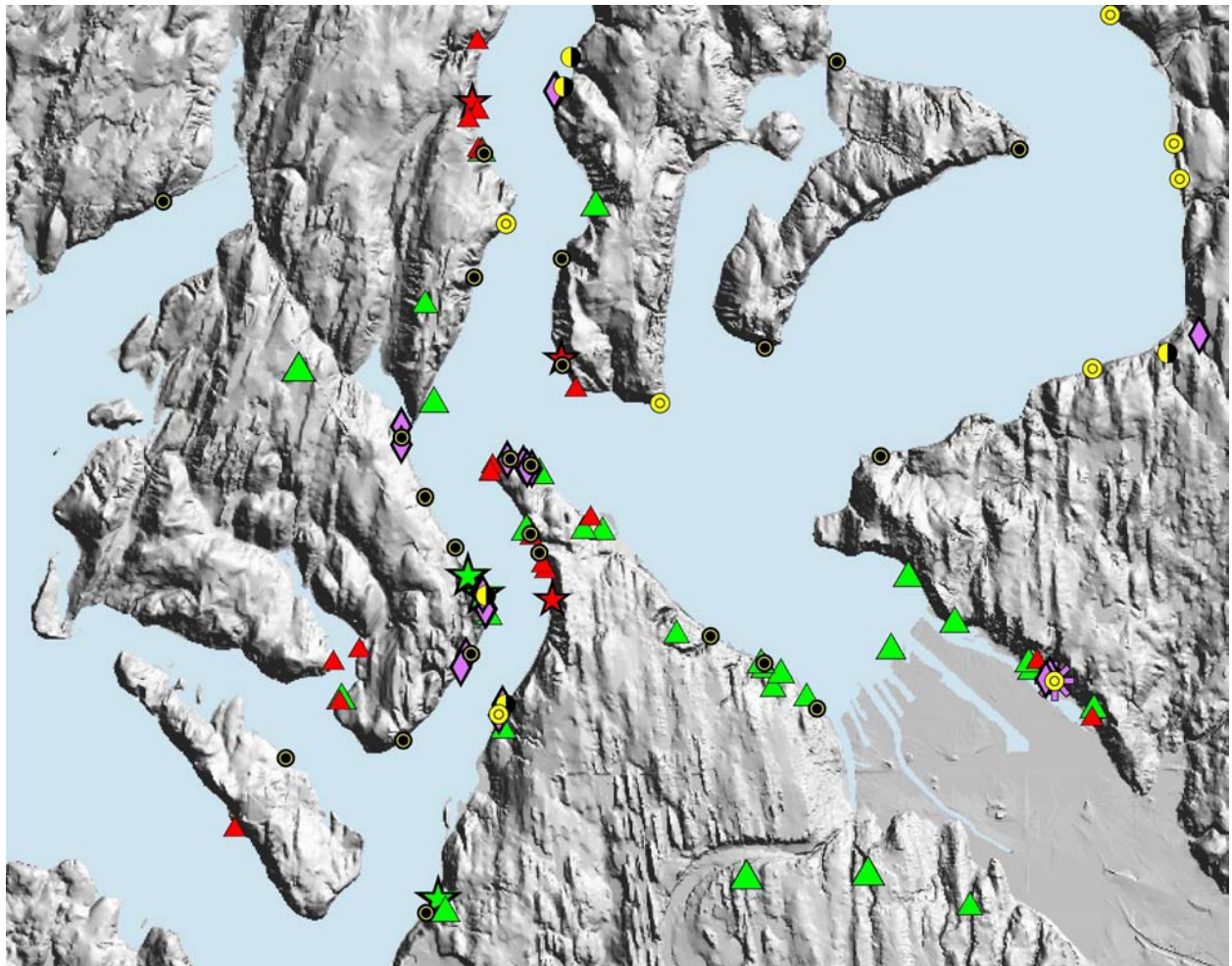


Figure 2. Map quadrangles for the City of Seattle

## INVESTIGATIONS AND RESULTS

### COMPONENT 1—REGIONAL STRATIGRAPHY AND CHRONOLOGY

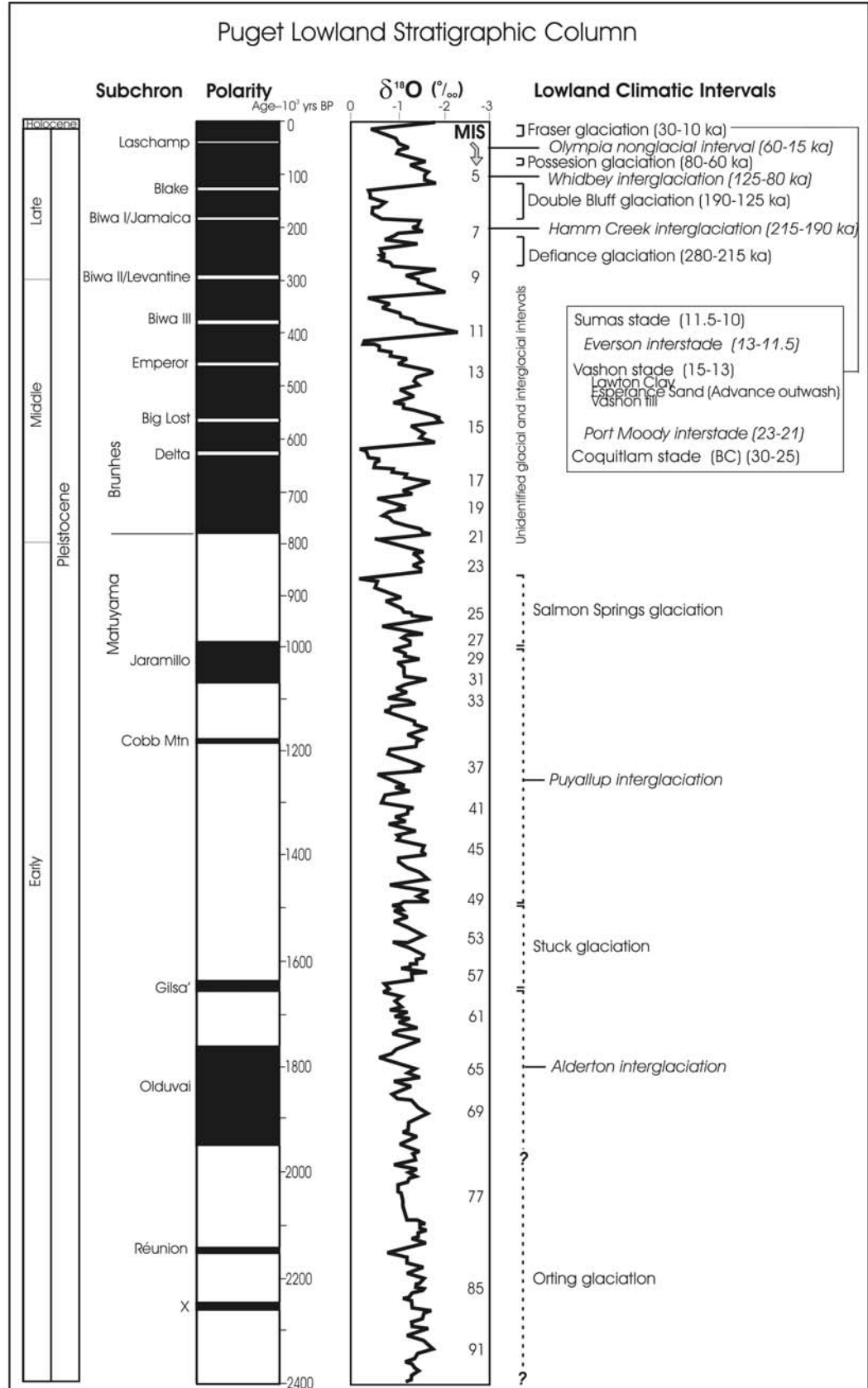
We have produced a chronological and lithologic composite section of glacial and nonglacial deposits in the central Puget Lowland that is being used to evaluate the distribution, correlation, and deformation of individual geologic units across the region, based on extensive field and laboratory analyses (e.g., Figure 3). We are writing several significant publications this year based on this work, for inclusion in upcoming volumes on Landslides in Seattle and the Geology of Washington. We have established the regional nomenclature, unit descriptions, and updated stratigraphic timescale (Figure 4) that are being used by scientists, local agencies, consultants, and upcoming USGS map products being developed by our group and others. Through collaboration with USGS scientists we have shown that the stratigraphic units identified at type sections on Whidbey Island, north of Seattle, can be mapped in the Tacoma area, and we have newly identified deposits from climatic stages previously undocumented in the Lowland.



**Figure 3.** Map of analytic samples of Quaternary sediments collected, dated, and/or compiled by the Seattle-Area Geologic Mapping Project. Key: circles = paleomagnetic samples, diamonds = IRSL age samples, triangles and stars =  $^{14}\text{C}$  age samples, snowflake = fission-track age sample

**Figure 4.**

Comparison of the marine oxygen-isotope curve stages (MIS) using the deep-sea oxygen-isotope data, global magnetic polarity curve, and ages of climatic intervals in the Puget and Fraser lowlands (modified from Booth et al., 2003, and original references cited therein). Ages for the Defiance glaciation and Hamm Creek interglaciation are from Troost et al. (2004).

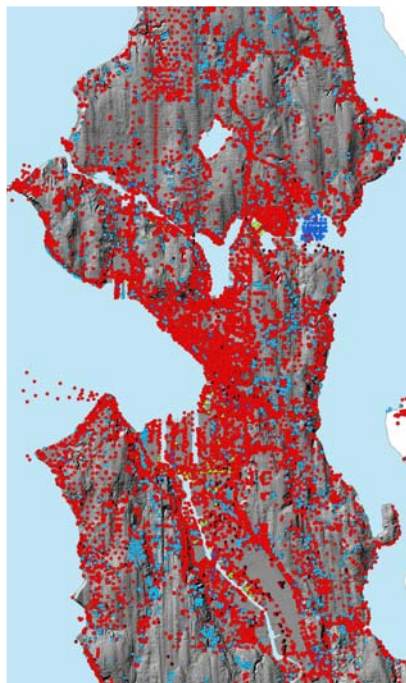




## COMPONENT 2—SUBSURFACE GEOLOGIC DATABASE FOR THE CITY OF SEATTLE

We are continuing to add to a comprehensive subsurface geologic database for the City and surrounding regions (Figure 5), funded by a combination of local agencies and USGS NEHRP. The database has been fully designed; its population is up-to-date for data held by the City of Seattle and many of the surrounding cities and contains more than 65,500 individual exploration sites. Within the City of Seattle alone, over 6000 separate geotechnical reports, which include over 30,000 individual exploration sites. They have been obtained from the City's Department of Planning and Development office (DPD), submitted from private geotechnical consultants in support of building permit applications; from the in-house soils laboratory of Seattle Public Utilities (SPU); and from the SPU Vault, King County Department of Natural Resources Technical Library, the Washington Department of Ecology, and private consultants. We are continuing to collect and enter data from the City of Seattle.

Our progress through 2004 in populating the main tables of the database is as follows:

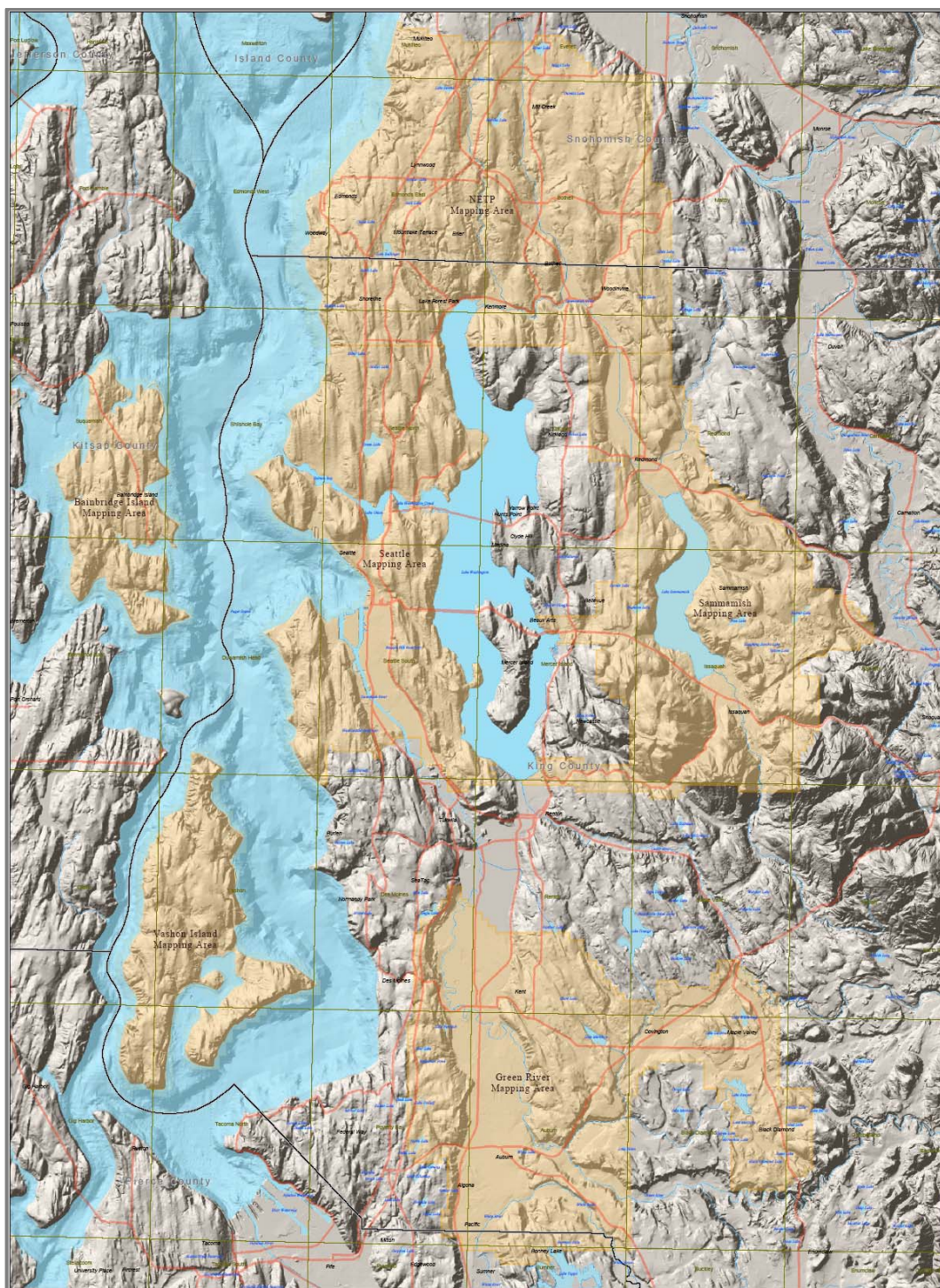


	<b>Total area— to date (11/13/04)</b>	<b>Seattle only— to date (11/13/04)</b>
DOCUMENTS	12,650	6,070
POINTS	65,600	30,500
LAYERS	267,900	128,750

Due to its increasing size, data entry limitations, and performance issues, the database has been converted from an MS Access database ArcView GIS platform to an ArcSDE geodatabase running on a Sun server with Oracle database software.

We provide quarterly database updates to our partners and some research affiliates. The GIS department at the City of Seattle receives the data and keeps their intranet files current for desktop use throughout the agency.

**Figure 5.** Hillshade of Seattle topography showing exploration points, most of which are geotechnical borings (red dots).



**Figure 6.** Current areas of coverage; tan highlight indicates the geographic coverage of the geologic database.

### **COMPONENT 3—SURFICIAL GEOLOGIC MAPS OF THE CITY OF SEATTLE**

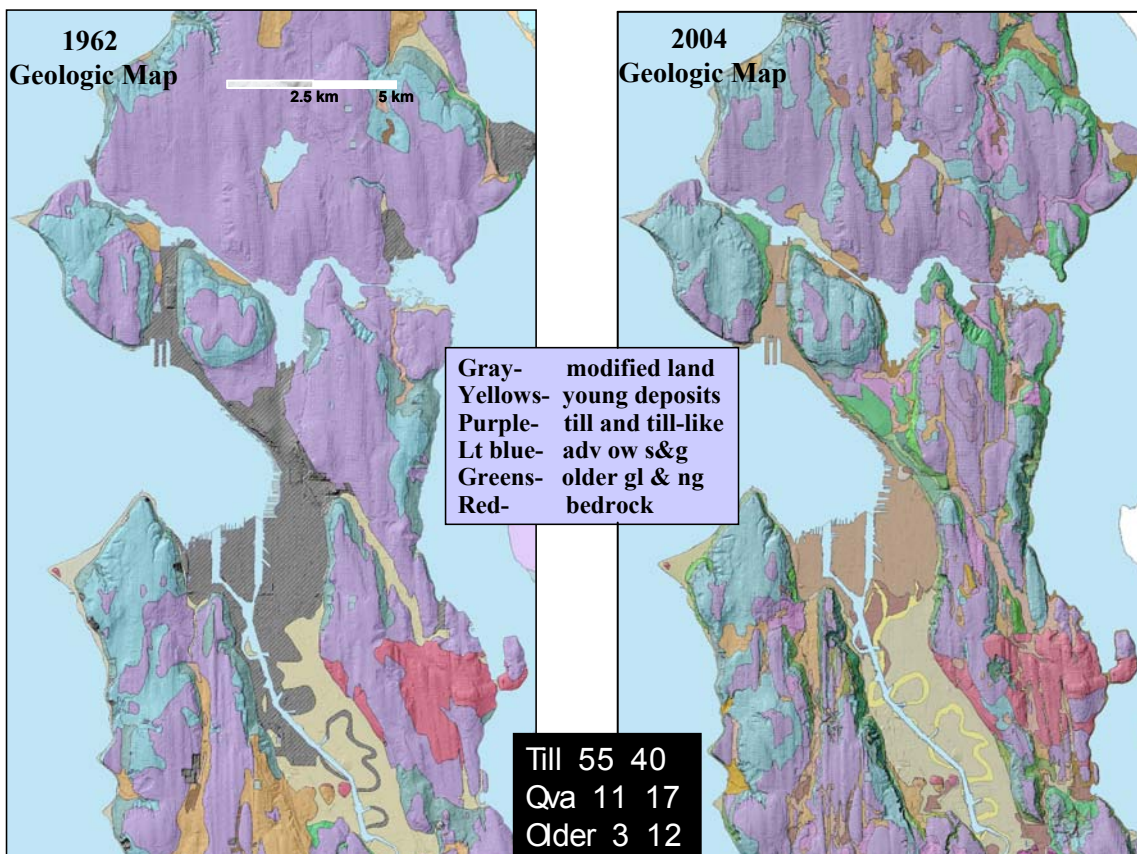
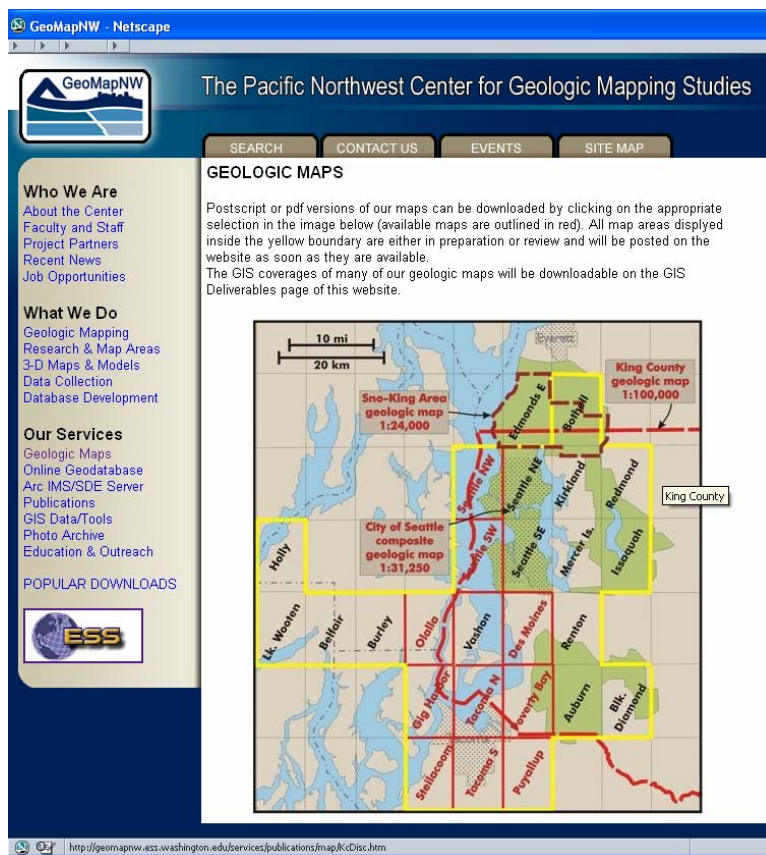
We have completed new geologic map coverage for the City, based on a combination of field investigations (coastal and river-valley bluffs, excavations, landslide scars) and near-surface borehole data. The Seattle SE and NE quadrangles have been submitted for USGS technical



review; although we continue to add to the database for all four quadrangles as new documents are acquired from the City and consultants. As the fully reviewed maps receive USGS Team Approval, they are available for viewing on the center's web site: <http://geomapnw.ess.washington.edu/> (Figure 6).

**Figure 7.** Index-map interface for downloading/viewing geologic maps with completed technical review.

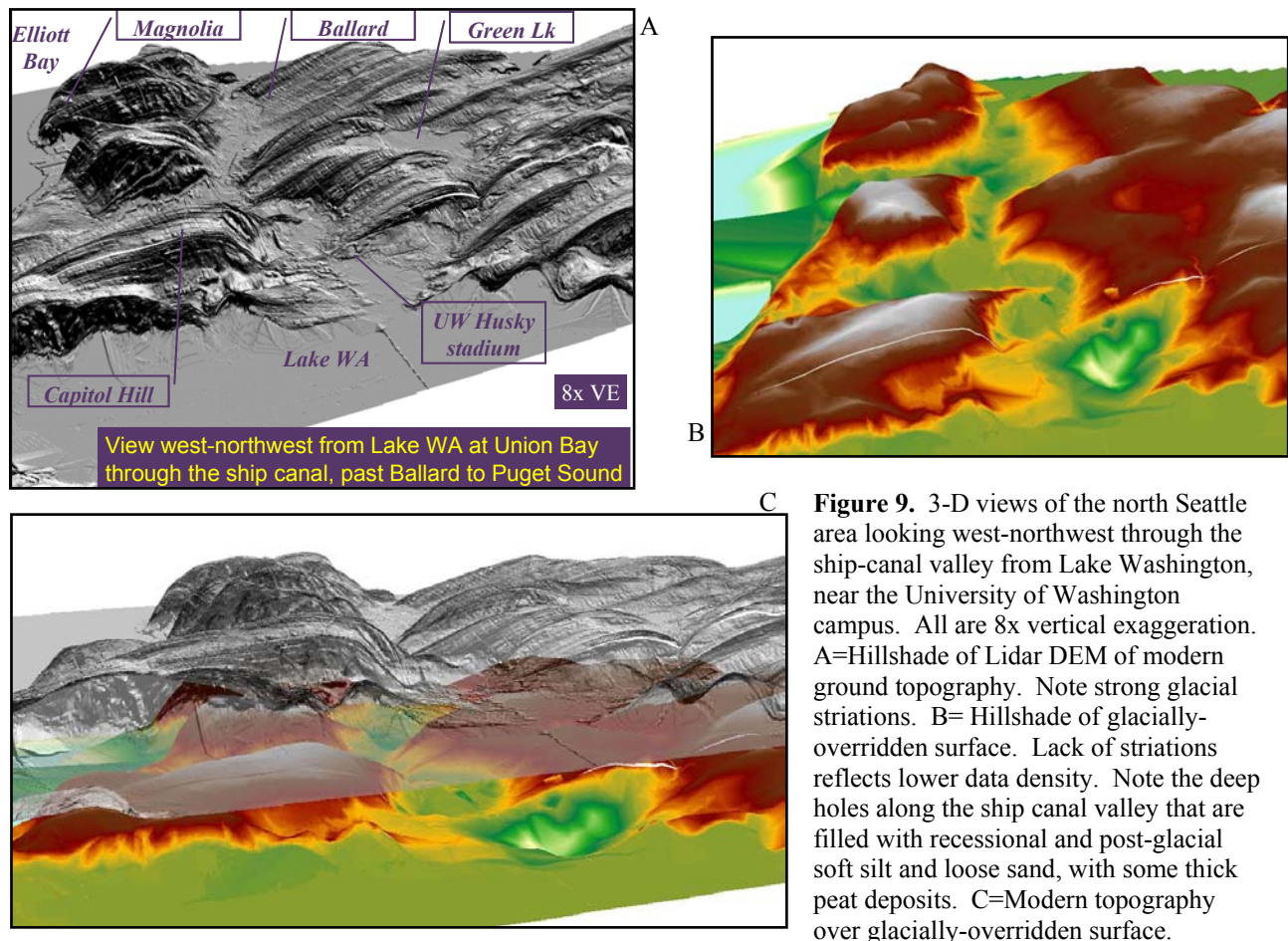
**Figure 8.** Comparison of old and new geologic maps of Seattle. The numbers in the black box represent percent of land area mapped as the designated geologic unit, with the 1962 map percentages in the left column and the 2004 map percentages in the right column.



#### COMPONENT 4—THREE-DIMENSIONAL GEOLOGIC MODEL OF THE CITY OF SEATTLE

Our progress on this component of the project has been significantly slower than anticipated, primarily because the project expertise for its development must be shared with enhancing the Internet presence and database access for the project. We have chosen to accelerate the latter efforts at the expense of 3-D mapping. This is an acknowledgement that our major funding sources have placed a very high priority on public access to the data, a goal that is compatible with USGS collaborator requests as well.

Our work continues on the 3-D effort, however, with an emphasis on development of layer thicknesses to facilitate modeling efforts. For example, we developed a map of the depth to glacially-overridden material in Seattle. This also provides the thickness of post-glacial deposits and artificial fill. This map was initiated by repeated queries of the database to delineate the elevations of certain geologic materials of certain densities. Of the 9000 points provided by the database query, we then added 1500 manually checked points. The surface maps, in combination with their supporting information from the database, provide an excellent foundation for developing 3-D geologic maps, where the nature and location of subsurface geologic contacts are constrained by borehole interpretations and the known or inferred processes of deposition. The surface of glacially-overridden material can be displayed in 3-D for aiding geologic interpretation and for presentation purposes (Figure 7).



**Figure 9.** 3-D views of the north Seattle area looking west-northwest through the ship-canal valley from Lake Washington, near the University of Washington campus. All are 8x vertical exaggeration. A=Hillshade of Lidar DEM of modern ground topography. Note strong glacial striations. B= Hillshade of glacially-overridden surface. Lack of striations reflects lower data density. Note the deep holes along the ship canal valley that are filled with recessional and post-glacial soft silt and loose sand, with some thick peat deposits. C=Modern topography over glacially-overridden surface.

## COMPONENT 5—EDUCATION AND TECHNICAL OUTREACH

This is an ongoing effort with steadily increasing attention and influence. It is anticipated to continue throughout the duration of the project. Specific activities for this component through the end of 2004 are summarized in the following table:

ACTIVITY	DATE	AUDIENCE
<b>SHORT COURSES—1999 - 2003</b>		
Quaternary Geology of the Central and Southern Puget Lowland (3 days including a 1-day field trip)	April 1999 and Sept 2000	Consultants, Agency Staff, Public
Quaternary Geology of the Central and Southern Puget Lowland	Jan 2000	Nelson Couvrette Associates
Quaternary Geology of the Central and Southern Puget Lowland (2 days including field trip)	May 2000	Landau Associates
Puget Lowland Geologic Framework (1 day)	Oct 2001	King County Wastewater Treatment Division and its consultants
Field classification and geology for drillers	September 2002	Department of Ecology-supported course for well-drilling professionals
Puget Lowland Geologic Framework (1 day)	December 2002	King County Wastewater Treatment Division and its consultants
Quaternary Geology of the Central and Southern Puget Lowland (3 days including a 1-day field trip)	May 2003	Consultants, Agency Staff, Public
Puget Lowland Geologic Framework (1 day)	January 2003	King County Wastewater Treatment Division and its consultants
<b>SHORT COURSES—2004</b>		
Quaternary and Engineering Geology of the Central and Southern Puget Sound Lowland (2 days including a 1-day field trip)	May 2004	City of Seattle technical staff
<b>FIELD TRIPS—1999 - 2003</b>		
Geology of the Central Puget Lowland	June 1999	Northwest Geological Society
Geology of Seattle	June 1999 and Aug 2000	City of Seattle Staff
Geology of Seattle	Sept 2000	UW Department of Geology and Geophysics
Geology of the Seattle Southwest Quad	July 2000	Technical Advisory Group Members
Quaternary Geology of the Central and Southern	June 2000	Association of

Puget Lowland (2-day)		Engineering Geologists
Prehistoric Earthquake and Tsunami in the Puget Sound area	Sept 2000	WSSPC attendees: state geologists and emergency managers
Geology of Seattle	Oct 2001	Department of Earth and Space Sciences, Univ. of WA alumni
Geology of the Seattle Area	June 2002	Northwest Geological Society
Geology of Seattle	Nov 2002	Department of Earth and Space Sciences, Univ. of WA alumni
Geology of Seattle	Oct 2003	City of Seattle staff
Seattle Fault	Oct 2003	Monorail Consultants
Geology of the Seattle Area	Nov 2003	Association of Women Geoscientists
Quaternary Geology of Seattle	Nov 2003	Geological Society of America, Annual Meeting,
<b>FIELD TRIPS—2004</b>		
Geology of Seattle	July 2004	League of Women Voters
<b>TECHNICAL MEETINGS—1999 - 2003</b>		
USGS Workshop on Geologic Hazards in the Puget Lowland	Nov 2000	Emergency Management and Geo/Eng Professionals
Project Updates	Quarterly	City of Seattle departments; King County
ANSS Advisory Committee (Siting sub-committee)	Quarterly, appx.	USGS, consultants, state
Seattle Geology	March 2003	Seattle Emergency Management, city staff
Workshop on Geologic Research in the Seattle Area	October 2003	Seattle Monorail Project; USGS; Washington Dept. of Natural Resources
Technical Advisory Group Meetings	Semi-annual	TAG Members
Archiving and Dissemination of Geotechnical Data; COSMOS/PEER-Lifelines Project 2L02	Semi-annual	CalTrans, CEC, PG&E, PEER, USGS, CGS, UCB, USC, and others
Technical Advisory Group Meetings	Semi-annual	TAG Members
<b>TECHNICAL MEETINGS—2004</b>		



Mercer Island and the Seattle Fault (convener)	June 2004	City Mercer Island department managers
Technical Advisory Group Meetings	Semi-annual	TAG Members
Archiving and Dissemination of Geotechnical Data; COSMOS/PEER-Lifelines Project 2L02	Semi-annual	CalTrans, CEC, PG&E, PEER, USGS, CGS, UCB, USC, and others
<b>CONFERENCES—1999 - 2003</b>		
Co-convener of the Seattle Urban Geologic Hazards Workshop	February 1999	ca. 200 agency staff and private consultants
Evening Forum on the Quaternary Geology of the Puget Lowland	August 1998; October 2000	2 <sup>nd</sup> and 3 <sup>rd</sup> Symposia on the Hydrogeology of Washington State
Geology of Seattle at the Seismological Society of America's Annual Meeting public forum	April 1999	SSA attendees and general public
Many individual presentations	ongoing	Professionals and research community
Convened a 1.5-day symposium on the Quaternary Geology of the Puget Lowland	April 2000	GSA attendees
Nisqually Earthquake symposium Seismological Society of America's Annual Meeting	April 2001	SSA attendees and general public
GSA North-Central Section Meeting Special Workshop on 3-D Mapping and Groundwater Modeling	April 2001	GSA Attendees
National Association of Geology Teachers, Western Division Meeting	June 2001	NAGT attendees and professionals
Convened symposium on the geology of glaciated regions at Geological Society of America annual meeting	November 2001	GSA attendees
Symposium on the Nisqually earthquake	April 2002	Annual meeting, Seismological Society of America
Symposia on the Quaternary Geology of the Puget Lowland and the Nisqually Earthquake (co-convenors and presenters)	April 2002	GSA Cordilleran Section meeting
3-D mapping workshop	October 2002	GSA Annual Meeting
Symposium on the Quaternary Geology of the Puget Lowland (co-convenors and presenters)	November 2003	GSA Annual Meeting
Hosted an exhibit booth at GSA national meeting in Seattle	November 2003	GSA Annual Meeting
<b>CONFERENCES—2004</b>		
Invited Poster, Poster Award	September 2004	AEG Annual Meeting

Invited Poster	November 2004	GSA Annual Meeting
<b>PUBLIC MEETINGS AND SELECTED INVITED TALKS—1999 - 2003</b>		
Co-convener, Urban Seismic Hazards Mapping Project Workshop	February 1999	USGS, UW, local agencies, public
Project Impact Disaster Saturdays: Display of "The Geology of Seattle" complete w/geologic samples and stratigraphic models	All, 1999, 2000, and 2001	Public
Ground Failures from the Nisqually Earthquake and the Geology of Seattle	Multiple presentations	CPARM; emerg. managers; Univ. Puget Sound, K-12 classes
Mapping the Geology of Seattle	February 2001	Assoc. of Women in Science; Assoc. for Women Geoscientists
NOAA Tsunami Workshop	February 2001	Emergency managers
Invited presentations at Seismological Society of America annual meeting and Geological Society of America Cordilleran section meeting	April 2002	SSA, GSA
The Seattle-Area Geologic Mapping Project	October 2002	Local chapters, Association of Engineering Geologists & American Society of Civil Engineers
Brown-bag presentations on Seattle-area geology to local consulting firms	June 2002, September 2002	GeoEngineers; Landau and Associates
Geology and Rivers	March 2003	Center for Water and Watershed Studies seminar series, University of Washington
Geology and Rivers in the Puget Lowland	June 2003	American Water Resources Association, monthly chapter meeting
Faults Beneath our Feet (moderator/host)	November 2003	Geological Society of America Public Forum
<b>PUBLIC MEETINGS AND SELECTED INVITED TALKS—2004</b>		
Glacial geology, landforms and deposits, and engineering applications of geology	April 2004	Civil Engineering 427 (Engineering Geology)
Shoreline Geology and Puget Sound Landscapes	May 2004	Puget Sound Beach Naturalists program, Seattle Aquarium

New Findings on the Geology of the Puget Lowland	May 2004	Local chapter, Association of Engineering Geologists
Geology and Hydrogeology of Vashon-Maury Island	April and September 2004	County and local groundwater committee
The SGMP: Advancing Quaternary Chronology in the Central Puget Lowland	April 2004	Western Washington University seminar speaker
Open House for newly created center: The Pacific Northwest Center for Geologic Mapping Studies	May 2004	Professors, researchers, consultants, agency staff, students
GIS and Geologic Mapping	September 2004	Special Librarians Annual Meeting
Mapping the Geology of the Greater Seattle Area: Infiltration, Peat Bogs and Volcanic Ash	November 2004	King County Science Forum, technical and public attendees
Origin of Puget Sound: Landforms and Landslides	November 2004	University of Puget Sound, guest lecture
Engineering Geology of Seattle and the Pacific Northwest Center for Geologic Mapping Studies	November 2004	Geo-Institute, Graduate Students and Civil Engineering Dept, UW

**Local Agency and Public Outreach.** Because of the potential utility of the geologic map products, and because of the efforts being invested by this project on behalf of geologic studies by *all* scientists throughout the region, we have received unprecedented support from local governments. The value of these efforts has been directly articulated and is more substantively demonstrated by the successful leveraging of USGS NEHRP funds (see *Financial Notes* section, below).

The geologic and engineering consultants of the region recognize our leadership in defining the stratigraphy, lithology, and geologic history of this area. They frequently solicit our opinions regarding various specific sites, and they utilize our database and our mapping efforts in their own investigations, which we provide in exchange for additional data. They also now utilize the nomenclature and color scheme for the region that we have established through this project.

City of Seattle and King County Wastewater Treatment Division employees and their consultants are using our database and map products at their desktops. In addition, anyone with an internet provider can access downhole data from our website.

**Technical Advisory Group (TAG).** A TAG was established early in our first year to enhance communication between this project and the end users of the products, consultants and agency representatives. Its membership (53 counting Troost and Booth) emphasizes senior members of the region's geologic, geotechnical, hydrogeologic, and engineering consulting firms; and

representatives from state, city, and local agencies who will be both the major users and the major contributors:

**Consulting Firms**

AMEC  
Aspect Consulting LLC  
Associated Earth Sciences  
Boeing Aerospace Company  
Cascade Drilling  
CDM Jessberger  
CH2M Hill  
R. Free Consulting  
Galster Consulting  
GeoEngineers, Inc.  
Golder Associates, Inc.  
Hart Crowser  
Herrera Consultants  
HWA Geosciences  
Landau Associates  
Robinson & Noble, Inc.  
Roth Consulting  
SCS Engineers  
Shannon & Wilson, Inc.  
SLR Corp  
Terra Associates  
Tubbs Geosciences  
Udaloy Environmental Services  
URS Corporation  
Yonemitsu Geological Services

**Agencies**

City of Seattle Dept. of Planning & Dev.  
Seattle Public Utilities  
Seattle Parks Department  
City of Tacoma  
Island County Health Department  
King County Dept of Nat. Res., GW Div.  
King County Wastewater Treatment Div.  
King County DDES  
Port of Tacoma  
US Army Corps of Engineers  
US EPA  
USGS – Water Resources  
USGS – Geologic Divisions  
University of Washington  
WA Dept. Nat. Res., Div. of Geology &  
Earth Res. & BSSD  
Washington Department of Ecology  
Washington Dept of Transportation



**NON-TECHNICAL SUMMARY**  
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**NEHRP Element:** I, Pacific Northwest region   **Keywords:** Geologic Mapping,  
Surficial Deposits, Age Dating, Tectonic Structures

Many engineering applications in urban and urbanizing areas are impacted by the spatial distribution of geologic materials and the sequence and history of their deposition. This project is developing a detailed understanding and representation of the three-dimensional distribution of geologic materials beneath Seattle and the surrounding urban and urbanizing region. To date, we have acquired and organized over 65,500 items of geologic information, representing a substantial start on of the vast amount of existing data; in combination with our ongoing field investigations, we are preparing and publishing the geologic maps to display this information for scientists, agencies, and the public.

## REPORTS PUBLISHED

### 1998-2003

#### *Manuscripts and abstracts:*

- Barnhardt, W.A., Kayen, R.E., Palmer, S., Troost, K.G., and Sherrod, B.S., 2001, Ground deformation at the Port of Seattle during the Nisqually earthquake: Seismological Research Letters, v. 72, no. 3, p. 391.
- Blouke, K., Shimel, S. A., Troost, K. G., O'Neal, M. A., and Booth, D. B., 2002, Spatial database for enhanced geologic mapping in Seattle, WA: Geological Society of America, Abstracts with Program, vol. 34, no. 5, Cordilleran Section Meeting, Corvallis, OR, May 13-15, 2002.
- Booth, D. B., R. A. Haugerud, and Troost, K. G., 2003, Geology, Watersheds, and Puget Lowland Rivers: chapter in D. Montgomery, S. Bolton, and Booth, D. B., eds., Restoration of Puget Sound Rivers: University of Washington Press, p. 14-45.
- Booth, D. B., Troost, K. G., and Hagstrum, J. T., in review, Deformation of Quaternary strata and its relationship to crustal folds and faults, central Puget Lowland, Washington: submitted to Geology.
- Booth, D. B., Troost, K.G., and Shimel, S.A., 2002, Geologic mapping at 1:12,000 scale across the City of Seattle: Geological Society of America, Abstracts with Program, vol. 34, no. 5, Cordilleran Section Meeting, Corvallis, OR, May 13-15, 2002.
- Booth, D.B., 2002, The landscape of western Washington---overburden and underburden: Geological Society of America, Abstracts with Program, vol. 34, no. 5, Cordilleran Section Meeting, Corvallis, OR, May 13-15, 2002.
- Booth, D.B., and Troost, K.G., 1998, Tectonic deformation of Pleistocene deposits in the central Puget Lowland, Washington State: Geological Society of America, Abstracts with Programs, Annual Meeting, v. 30.
- Booth, D.B., Troost, K.G., and Hagstrum, J.T., 1999, Character and age of tectonically deformed Pleistocene Deposits in the central Puget Lowland, Washington state: Seismological Research Letters, v. 70, no. 2, p. 234.
- Booth, D.B., Troost, K.G., and Shimel, S.A., 2003, Landfall of the Seattle Fault Zone, West Seattle, WA: Abstracts with Program, Geological Society of America, Annual Meeting, Seattle, November 2-5, 2003, p.479.
- Booth, D.B., Troost, K.G., Clague, J.J., and Waitt, R.B., 2003, The Cordilleran ice sheet: chapter in Gillespie, A., Atwater, B., and Porter, S. C., eds., Advances in Research in Quaternary Geology of the United States: International Union for Quaternary Research.
- Booth, D.B., Troost, K.G., Hagstrum, J.T., Blakely, R.J., and Thorson, R.M., 2000, Geologic Evaluation of Tectonic Deformation in the Central Puget Lowland, Washington State: Abstracts with Programs, 96th Annual Meeting Cordilleran Section, Vancouver, British Columbia, April 27-29, 2000.

- Booth, D.B., Wells, R.E., and eleven others, 2001, Chimney damage patterns in the greater Seattle area from the Nisqually Earthquake of February 28, 2001: *Seismological Research Letters*, v. 72, no. 3, p. 395.
- Borden, R.K., and Troost, K.G., 2001, Late Pleistocene Stratigraphy in the south-central Puget Lowland, West-Central Pierce County, Washington: Olympia, Washington State Department of Natural Resources, Report of Investigations 33, 33 p.
- Hagstrum, J.T., Booth, D.B., and Troost, K.G., 2000, Magnetostratigraphy and Paleomagnetic Correlation of Pleistocene Deposits in the Central Puget Lowland, Washington: Abstracts with Programs, 96th Annual Meeting Cordilleran Section, Vancouver, British Columbia, April 27-29, 2000.
- Hagstrum, J.T., Booth, D.B., Troost, K.G., and Blakely, R.J., 2002, Magnetostratigraphy, paleomagnetic correlation, and deformation of Pleistocene deposits in the south-central Puget Lowland, Washington: *Journal of Geophysical Research–Solid Earth* 107 (B4): art. no. 2079 Apr 10 2002.
- Hagstrum, J.T., Mahan, S.A., Troost, K.G., and Booth, D.B., 2003, Magnetostratigraphy, optical dating, and vertical deformation of Pleistocene deposits in the South Central Puget Lowland: Abstracts with Program, Geological Society of America, Annual Meeting, Seattle, November 2-5, 2003, p. 79.
- Haugerud, R.A., and Booth, D.B., 2000, A Synoptic View of Vashon Glaciation: The Movie: Abstracts with Programs, 96th Annual Meeting Cordilleran Section, Vancouver, British Columbia, April 27-29, 2000.
- Haugerud, R.A., Troost, K.G., Harp, E.L., Wegmann, K.W., Sherrod, B.L., Pratt, T.L., and Kramer, S.L., 2001, Regional map view of ground deformation associated with the Nisqually earthquake, 28 February 2001, *Seismological Research Letters*, v. 72, no. 3, p. 393.
- Ludwin, R.S., James, K., Jonientz-Trisler, C., Buerge, D., Pickens, J., Troost, K., and Skaret, M., 2003, Water-serpent myths of Puget Sound natives may refer to the a.d. 900 Seattle earthquake: Abstracts with Program, Geological Society of America, Annual Meeting, Seattle, November 2-5, 2003, p. 80.
- Mahan, S. A., Booth, D. B., and Troost, K. G., 2000, Luminescence dating of glacially derived sediments: a case study for the Seattle Mapping Project: Abstracts with Programs, 96th Annual Meeting Cordilleran Section, Vancouver, British Columbia, April 27-29, 2000.
- Mahan, S.A., Troost, K.G., Hagstrum, J.T., and Booth, D.B., 2003, Dating sediments older than 100ka in the Seattle-Tacoma urban corridor: A test for infrared stimulated luminescence and thermoluminescence on fine grain deposits: Abstracts with Program, Geological Society of America, Annual Meeting, Seattle, November 2-5, 2003, p. 79.
- Mahoney, J. B., Brandup, J., Troost, K.G., and Booth, D.B., 2000, Geochemical discrimination of episodic glaciofluvial sedimentation, Puget Lowland, Washington: Abstracts with Programs, 96th Annual Meeting Cordilleran Section, Vancouver, British Columbia, April 27-29, 2000.

- Mahoney, J.B., Prindville, S., Troost, K.G., and Booth, D.B., 2004, Geochemical characteristics of glaciogenic sediments, Puget Lowland, Washington: Abstracts with Program, Geological Society of America, Annual Meeting, Seattle, November 2-5, 2003, p. 79.
- Odum, J., Stephenson, W., Frankel, A., Williams, R., and Troost, K., in review, Shear-wave velocity from two 150 m boreholes in Seattle, WA: U. S. Geological Survey open-file report.
- Odum, J., Stephenson, W., Frankel, A., Williams, R., and Troost, K., 2003, Shear-wave velocity from two 150 m boreholes in Seattle, WA: Abstracts with Program, Geological Society of America, Annual Meeting, Seattle, November 2-5, 2003, p. 645.
- Porter, S.C. and Troost, K.G., 2003, Glaciation and sedimentary environments in the Pacific Northwest during marine isotope stage 3: Abstracts with Program, Geological Society of America, Annual Meeting, Seattle, November 2-5, 2003, p. 215.
- Sherrod, B., Booth, D.B., Troost, K.G., Koppes, M., and Mahan, S., 2000, The I-5/Atlantic Street site near downtown Seattle, Washington: a case for late Quaternary tectonic deformation along the Seattle Fault or glaciotectonic deformation?: Abstracts with Programs, 96th Annual Meeting Cordilleran Section, Vancouver, British Columbia, April 27-29, 2000.
- Sherrod, B.L., Haeussler, P.J., Wells, R., Troost, K., and Haugerud, R., 2001, Surface rupture in the Seattle fault zone near Bellevue, Washington, *Seismological Research Letters*, v. 72, no. 2, p. 253.
- Shimel, S.A., Blouke, K., O'Neal, M.A., Troost, K.G., and Booth, D.B., 2001, Spatial database for enhanced geologic mapping in Seattle, WA: Geological Society of America, Annual Meeting, Boston, MA, November 4-7, 2001.
- Shimel, S.A., Troost, K.G., and Booth, D.B., 2002, Geologic controls on site response and ground failures in Seattle during the 2001 Nisqually earthquake: Geological Society of America, Abstracts with Program, vol. 34, no. 5, Cordilleran Section Meeting, Corvallis, OR, May 13-15, 2002.
- Shimel, S.A., Troost, K.G., and Booth, D.B., 2003, Current geologic mapping in the greater Seattle area Washington State: Abstracts with Program, Geological Society of America, Annual Meeting, Seattle, November 2-5, 2003, p.75.
- Troost, K.G. and Booth, D.B., 1999, The Seattle geologic mapping project: Geological Society of America, Abstracts with Programs, Annual Meeting, v. 31.
- Troost, K.G., 2000, The Olympia Nonglacial Interval in the Southcentral Puget Lowland, Washington: Abstracts with Programs, 96th Annual Meeting Cordilleran Section, Vancouver, British Columbia, April 27-29, 2000.
- Troost, K.G., 2002, Summary of the Olympia nonglacial interval (MIS 3) in the Puget Lowland, Washington: Geological Society of America, Abstracts with Program, vol. 34, no. 5, Cordilleran Section Meeting, Corvallis, OR, May 13-15, 2002.
- Troost, K.G., Booth, D.B., and Laprade, W.T., 2004, Quaternary geology of Seattle: in Swanson, T.W. ed., *Western Cordillera and Adjacent Areas*, The Geological Society of America, Field Guide 4, Boulder, CO., p. 267-284.



- Troost, K.G., Booth, D.B., Haugerud, R.A., and Barnett, E.A., 2002, Status and findings from 1:24,000 scale geologic mapping in the Puget Lowland, WA: Geological Society of America, Abstracts with Program, vol. 34, no. 5, Cordilleran Section Meeting, Corvallis, OR, May 13-15, 2002.
- Troost, K.G., Booth, D.B., Mahan, S.A., and Hagstrum, J.T., 2003, Presence of mid-Pleistocene deposits (MIS4 through 8) in the Tacoma area: Did the Possession glacier make it to Tacoma?: Abstracts with Program, Geological Society of America, Annual Meeting, Seattle, November 2-5, 2003, p. 215.
- Troost, K.G., Booth, D.B., Shimel, S.A., Haugerud, R.A., Kramer, S.L., Kayen, R.E., and Barnhardt, W.A., 2001, Geologic controls on ground failures in Seattle and vicinity during the 2001 Nisqually earthquake, Seismological Research Letters, v. 72, no. 3, p. 393.
- Troost, K.G., Haugerud, R.A., Walsh, T.J., Harp, E.L., Booth, D.B., Steele, W.P., Wegmann, K.W., Pratt, T.L., Sherrod, B.S., and Kramer, S.L., 2001, Ground failures produced by the Nisqually earthquake, Seismological Research Letters, v. 72, no. 3, p. 396.
- Troost, K.G.; Booth, D.B.; Shimel, S.A.; Frankel, A.D., 2002, Geologic controls on site response and ground failures in Seattle during the 2001 Nisqually earthquake [abstract]: Seismological Research Letters, v. 73, no. 2, p. 214.
- Weaver, C. S., Troost, K. G., Booth, D. B., Frankel, A., Wells, R. E., Mullen, J., and Nolan, T., 1999, The Seattle urban seismic hazard mapping project: a USGS contribution to Seattle's Project Impact: Seismological Research Letters, v. 70, no. 2, p. 256.

## **2004**

### ***Manuscripts:***

- Booth, D.B., Troost, K.G., and Hagstrum, J.T., 2004, Deformation of Quaternary strata and its relationship to crustal folds and faults, central Puget Lowland, Washington: *Geology*, v-32(6).
- Booth, D.B., Wells, R.E., Givler, R., 2004, Chimney damage along the margin of the Seattle Basin during the 2001 Nisqually earthquake; *Bulletin of the Seismological Society of America*.

### ***Abstracts:***

- Troost, K.G. and Booth, D.B., 2004, Applications of a Geologic Database of the Greater Seattle Area, Western Washington, Program with Abstracts, 2004 Annual Meeting, Association of Engineering Geologists, Dearborn, Michigan, September 26-October 2, 2004, Changes to Program with Abstracts p. 5.
- Troost, K.G., Booth, D.B., O'Neal, M.A., Shimel, S.A., and Wisher, A.P., 2004, Improved aquifer susceptibility and infiltration mapping, Puget Sound, Washington, Abstracts with Program, 2004 Annual Meeting, The Geological Society of America, Denver, Colorado, November 7-10, 2004, p. A-578.

## **GEOLOGIC MAPS—current status (12/04):**

### ***In preparation***

Troost, K.G., Booth, D.B., Wisher, A.P., and Shimel, S.A., in review, Geologic map of Seattle: U.S. Geological Survey Open-File Report, scale 1:24,000.

Troost, K.G., Wisher, A.P., Booth, D.B., and Shimel, S.A., in review, Geologic map of the Kent and Auburn Areas: U.S. Geological Survey Open-File Report, scale 1:24,000.

### ***In review***

Booth, D.B., Troost, K.G., and Shimel, S.A., in review, Geologic map of the Seattle NE quadrangle: U.S. Geological Survey Scientific Investigations Map, scale 1:12,000.

Booth, D.B., Troost, K.G., and Shimel, S.A., in review, Geologic map of the Issaquah quadrangle: U.S. Geological Survey Scientific Investigations Map, scale 1:24,000.

Troost, K.G. and Booth, D.B., in review, Geologic map of the Steilacoom 7.5-minute quadrangle, Washington: U.S. Geological Survey Scientific Investigations Map, scale 1:24,000.

Troost, K.G., Booth, D.B., and Borden, R.K., in review, Geologic map of the Tacoma North 7.5-minute quadrangle, Washington: U.S. Geological Survey Scientific Investigations Map, scale 1:24,000.

Troost, K.G., Booth, D.B., and Shimel, S.A., in review, Geologic map of the Seattle SW quadrangle: U.S. Geological Survey Scientific Investigations Map, scale 1:12,000.

Troost, K.G., Booth, D.B., and Wells, R.E., in review, Geologic map of the Gig Harbor 7.5-minute quadrangle, Washington: U.S. Geological Survey Scientific Investigations Map, scale 1:24,000.

Troost, K.G., Booth, D.B., Wisher, A.P., and Shimel, S.A., in review, Geologic map of the Seattle SE quadrangle: U.S. Geological Survey Scientific Investigations Map, scale 1:12,000.

Troost, K.G., in review, Geologic map of the Puyallup 7.5-minute quadrangle, Washington: U.S. Geological Survey Scientific Investigations Map, scale 1:24,000.

Troost, K.G., in review, Geologic map of the Tacoma South 7.5-minute quadrangle, Washington: U.S. Geological Survey Scientific Investigations Map, scale 1:24,000.

### ***In press***

Booth, D.B. and Waldron, H.H., 2004, Geologic map of the Des Moines 7.5-minute quadrangle, Washington: U.S. Geological Survey Scientific Investigations Map 2855, scale 1:24,000.

Booth, D.B., and Troost, K.G., in press, Geologic map of the Olalla 7.5-minute quadrangle, Washington: U.S. Geological Survey Scientific Investigations Map, scale 1:24,000.

- Booth, D.B., Haugerud, R.A., and Sacket, J., in press, Geologic map of King County, Washington: U.S. Geological Survey Open-File Report, scale 1:100,000.
- Booth, D.B., Troost, K.G., and Shimel, S.A., in press, Geologic map of the Seattle NW quadrangle: U.S. Geological Survey Scientific Investigations Map, scale 1:12,000.
- Booth, D.B., Waldron, H.H. and Troost, K.G., 2004, Geologic map of the Poverty Bay 7.5-minute quadrangle, Washington: U.S. Geological Survey, Scientific Investigations Map 2854, scale 1:24,000.

## **FINANCIAL NOTES**

This project has been quite successful in leveraging the contribution of the USGS NEHRP funds through additional financial and in-kind support from other programs of the USGS and from local governments. Some of that support has been used to cover the initial shortfall of funds for the originally scoped NEHRP project (namely, the geologic map of the City of Seattle), some has been used to develop the scientific framework for Quaternary geologic investigations in the region (Component 1 of this project), and some has been used to expand the geographic scope of the effort into populated areas to the north, south, and east. Funding amounts are tabulated and also shown graphically below:

## Project Funding 2000-2004:

SOURCE	DIRECT FUNDING				
	2000	2001	2002	2003	2004
USGS: NEHRP	\$160,000	\$170,000	\$170,000	\$125,000	\$100,000
USGS: NCGMP	\$38,332	\$12,450	\$31,617	\$36,975	\$37,425
City of Seattle: DCLU	\$60,000	\$60,000	\$60,000	\$60,000	\$40,000
City of Seattle: SPU	\$50,000	\$25,000	\$25,000	\$25,000	\$25,000
Univ. of WA: CWWS	\$20,000	\$10,000	\$10,000	\$10,000	\$10,000
King Co. Wastewater		\$327,449	\$216,600	\$278,420	\$100,000
City of Bothell			\$15,000		
King Co. Groundwater			\$25,000		\$75,000
Seattle Monorail				\$20,000	\$40,000
Bainbridge Island					\$75,444
Mercer Island					\$50,000
	<b>\$328,332</b>	<b>\$604,899</b>	<b>\$553,217</b>	<b>\$555,395</b>	<b>\$552,869</b>

